Summary of Proposed Manufacturing R&D Task Priorities

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Solid State Lighting LED Manufacturing Roundtable Summary

Introduction

On April 18, 2012, nine LED experts gathered in Washington, DC, at the invitation of the DOE to develop proposed priority tasks for the Manufacturing R&D initiative. The meeting commenced with "soapbox" presentations from each of the participants, followed by a general discussion to define specific work needing attention. On May 2, 2012, the DOE also held an LED Roundtable Teleconference to accommodate six additional LED experts who were unable to attend the April 18 roundtable meetings. This report summarizes the conclusions of those meetings, including the proposed priority tasks, a summary of discussion points relevant to those selections, and a short summary of the soapbox presentations.

General Roundtable Attendee Comments

The main themes of the LED roundtable discussions were as follows:

- Substrates
  - There is a need for larger substrates which would drive the need for larger scale equipment and reduced raw materials costs.
  - Improved quality and consistency of products is required along with standard specifications.
  - Bulk growth processes need to be better understood and controlled.
  - There is a need for improved substrate fabrication processes.
  - There are opportunities for wafer standards to drive efficiency and consistency within the industry. Such standards would greatly clarify raw material requirements and help determine which substrate manufacturing processes are best, leading to cost reductions.
  - Substrate manufacturing could become a new priority task, however, improvement to substrate manufacturing will have a small impact on overall cost reductions for LED manufacturing.
- Epitaxy
  - There remains a need to continue reducing epitaxial wafer costs. Issues such as wavelength uniformity and reproducibility have an impact on cost, but it is important to consider end-to-end optimization of yields to improve overall costs rather than focus on any one step in the process. Hence further improvements in the epitaxial growth equipment should occur in conjunction with the development of other process equipment and process methodologies. Specific areas to address are improving in-situ and ex-situ monitoring/control, as well as platform stability.
  - It is important to continue the development of MOCVD equipment (i.e. Task M.L4); however, it is not felt to be a priority research area. Cost predictions indicate that future cost improvements (epitaxy cost per wafer area) will become more and more difficult to achieve. Therefore, future MOCVD equipment improvements will come in the form of increased process control, customization and fabrication integration.
  - There is also a need for more flexible MOCVD production equipment. Since it is predicted that manufacturers will continue to operate using a variety of wafer sizes (i.e. 2”, 4” and 6”).
- Wafer Processing
  - The main issue for wafer processing equipment suppliers is the need for flexibility to handle the wide range of substrate types and diameters currently used in production. Many customers place a high premium on low acquisition cost and still tend to modify their own equipment. Better partnering and standards would help the industry develop relevant equipment. Nevertheless the availability of such equipment is not regarded as a current roadblock.
  - The title of task M.L5 should be changed to ‘Wafer Manufacturing and Processing Equipment’.

- Phosphor Application
  - Phosphor and matrix materials comprise a significant cost for various package designs. Further improvements in application flexibility to meet the wide range of demands for current and new package designs is required along with suitable equipment to meet that demand.
  - The focus should be on improving phosphor application with emphasis on reducing overall system cost and improving performance.
- Test and Measurement
  - There is a need for a closer interaction between the end-user and the equipment manufacturer.
  - Improved detection of killer defects as early as possible in the wafer processing is an important requirement in order to reduce manufacturing costs. Developing equipment to enable cost effective hot testing of LEDs is also important. High speed equipment must replicate as closely as possible the actual 'hot' environment for optimum accuracy.
  - There is a need for increased speed, accuracy, and repeatability of testing and metrology equipment.
- Die Packaging
  - More efficient use of materials (either using less material or finding more affordable alternatives) will enable lower cost LED packages without forsaking performance.
- Luminaire Manufacturing
  - There is a need to improve the implementation of formal design for manufacturing.
  - LED lighting needs to venture away from existing form factors – the industry needs to move away from retrofit designs, since these are less capable of using all of the inherent benefits of LED lighting technology.
  - Next generation luminaires will incorporate a broader range of technologies to achieve specific form factors and enhanced performance attributes that make use of the advantages offered by LED-based sources. Large area surface emitters and flexible PCB designs with direct die attach are possible directions. Tunable systems will provide new functionality and drive the need for high speed test equipment capable of accurately capturing color point information to meet tightening specifications.
  - A modular approach to luminaire assembly/integration will help reduce costs through reduced SKU counts. The introduction of control solutions and field adaptable/configurable systems would add further value. Optics design for luminaires currently lack beam pattern standardization for LED light sources resulting in re-engineering and increased costs. Solutions might include the use of direct chip-on-board where no primary optics would be involved.
  - Standardization, particularly regarding the LED footprint could lead to lower costs and more efficient luminaire manufacture. Such a standard would limit the operating conditions as well as the type and number of LED components and would simplify the manufacturing process. However, premature standardization could be detrimental to the industry, limiting innovation. A possibility would be to develop some standards (e.g., Zhaga) for "workhorse" products while keeping other options open for new designs and top-end performance.
  - A closer linkage is required between the luminaire manufacturing process and product reliability such that all interactions are understood, the impact of manufacturing changes could be anticipated, and improved predictions of product reliability could be achieved during the design phase.
  - Novel approaches to reducing parts counts and complexity in luminaires should be encouraged. One example might be die bonding direct to the heat sink with printed dielectrics and connection circuitry in order to remove a number of thermal interface layers, improving performance and reducing costs.
  - A system level roadmap should be developed for luminaires and this should be mapped onto a technology level roadmap.

    - Luminaire cost projections in the roadmap should clearly reference the type of luminaire and should be supported by relevant price information.
- Other Comments
    - There is a need for improvements to yield and throughput across the whole manufacturing process. A definition for yield needs to be developed, however this is very difficult as LEDs are analog devices, and are binned by specific attributes, increasing the overall yield, but not addressing yield to tightly defined parameters.
    - More collaboration is needed in order to better advance LED manufacturing methods. A SEMATECH-like organization would potentially benefit the industry by providing a nexus for increased collaboration.

Proposed Priority Tasks

The following tables provide descriptions and metrics for the proposed priority tasks. The task tables shown do not reflect any modifications suggested by roundtable attendees. All comments, including suggested changes to each task description and metrics, are provided below each of the relevant task tables. These comments represent a summarized transcript of the general commentary and require further discussion at the Manufacturing R&D Workshop. The results of these discussions will guide the DOE in soliciting projects in the LED Manufacturing R&D Program during the coming year.

M.L1 Luminaire/Module Manufacturing		
Support for the development of flexible manufacturing of state-of-the-art LED modules, light engines, and luminaires. Suitable development activities will focus on advanced LED packaging and die integration (e.g. COB, COF, etc.), more efficient use of raw materials, simplified thermal designs, weight reduction, optimized designs for efficient manufacturing (such as ease of assembly), increased integration of mechanical, electrical and optical functions, and reduced manufacturing costs. The work should demonstrate higher quality products with improved color consistency, lower system costs, and improved time-to-market through successful implementation of integrated systems design, supply chain management, and quality control.		
Metric(s)	**Current Status**	**2015 Target(s)**
Downtime		50% reduction
Manufacturing Throughput		x2 increase
OEM Lamp Price	\$50/klm	\$10/klm
Assembly Cost (\$)		50% reduction every 2-3 years
Color Control (SDCM)	7	4

Roundtable Attendee Comments (M.L1)

Proposed changes to description:

- Designing LED products for manufacturing is important. This needs to be thought of as a manufacturing issue, not confined to product development. Text should be added to this task or a new task should be created to reflect this concept.
- The description should convey the need for cooperative efforts to help advance manufacturing process technology. Also, the description should emphasize that it is not so much the need for advanced LED packaging, but processes for incorporating LEDs into luminaires.
- This task should be modified to include emphasis on processes that would lead to reducing complexity by integrating and reducing the number of LED components. This will help lead to significant cost reductions. Examples of these process-level changes could include wafer-scale packaging and/or eliminating layers in order to get closer to a simple chip on heat sink.

Other comments:

- Attendees discussed the need for a domestic manufacturing base for robust quality optics.
- Consumers are expecting the cost of LED luminaires to reflect the same price decreases they have seen for LED packages. This expectation may be misplaced. The additional components and subsystems in an LED luminaire are not likely to fall in cost as rapidly as the LED sources, and manufacturers will not necessarily pass on all cost reductions to buyers except as competition demands.

M.L3 Test and inspection equipment		
Support for the development of high-speed, high-resolution, non-destructive test equipment with standardized test procedures and appropriate metrics for each stage of the value chain for semiconductor wafers, epitaxial layers, LED die, packaged LEDs, modules, luminaires, and optical components. Equipment might be used for incoming product quality assurance, in-situ process monitoring, in-line process control, or final product testing/binning. Suitable projects will develop and demonstrate effective integration of test and inspection equipment in high volume manufacturing tools or in high volume process lines, and will identify and quantify yield improvements.		
Metric	**2011 Status**	**2015 Target**
Throughput (units per hour)		x2 increase
Cost of ownership		2-3x reduction every 5 years
$/units per hour		
Attendee Suggested Metrics		
Yield of tool		
Reliability		

Roundtable Attendee Comments (M.L3)

Proposed changes to description:

- A clause on testing accuracy should be included in the task description. In addition, test gauge capabilities need to be specified and measured with respect to current industry standards. Specific areas requiring improved testing accuracy include the measurement of color coordinates and the unambiguous identification of killer defects.
- Methods for characterizing and improving reliability are an important priority. Customers are beginning to understand and increasingly focus on system reliability; therefore it is important that the industry develop methods for monitoring the impact of each manufacturing step on product reliability in order to facilitate better quality assurance and cost control of products. The description should be modified to express this need.
- ’High-capability’ should take the place of ‘high-resolution’ in the task description because resolution is only one aspect of the testing capability.

Proposed changes to metrics:

- A metric to measure the success of the reliability monitoring methods should be defined.
- A metric quantifying the yield or yield enhancements offered by the test and inspection tool needs to be added. This improvement could be quantified by specifying yield improvement or return on investment (ROI) within a certain time frame.
- ‘Yield of tool’ metric should require that yield improvements pay for the tool within 3 months of use.

Other comments:

- The need for yield increases through improved test and inspection equipment was discussed by the attendees.
- Rapid feedback of test results is important as this can significantly affect throughput of good product and overall product quality and cost.
- The ability to target a specific bin with high yield should be a priority within this task. Specifically kill ratio improvement, that is, the ability of an inspection tool to identify fatal defects, should be emphasized. Current kill ratios are around 50%, i.e. only 50% of the observed defects result in a failure.

- Hot testing speed and accuracy at the wafer level was identified as an important requirement.
- Metrology, reliability testing and predictive modeling are needed to enable “mapping” of lab scale reliability testing to final product lifetime.
- TM-21 provides a defined method to project lumen maintenance at the LED package level; however that standard is missing at the luminaire level (this is currently being worked on). In addition, there are no procedures for predicting future color quality or color shift.
- Manufacturing environment testing for optics will become more important as customer demand for verification of optical claims increases.

M.L6 LED Packaging		
Identify critical issues with back-end processes for packaged LEDs and develop improved processes and/or equipment to optimize quality and consistency and reduce costs.		
Metric	**2011 Status**	**2015 Target**
Packaged LED throughput		2x increase per year
Assembly Cost ($/klm)		50% reduction every 2-3 years
Cost of Packaging ($/mm^2)		50% reduction every 2-3 years
Cost of Package ($/klm)		50% reduction every 2-3 years

Roundtable Attendee Comments (M.L6)

Proposed changes to description:

- The emphasis of this task should be on enabling lower costs of LED packages without forsaking performance aspects. Emphasis should be placed on more efficient use of materials and better (or fewer) interfaces. These points should be incorporated into the task description. For example, AlN submount tiles are expensive (i.e. $15 per bare 4" square tile) and can add a significant cost per die. Suitable silicone materials are expensive.

Other comments:

- Many different package designs exist along with many different packaging technologies. The key is to choose the right package design approach for a specific application. Both high power and low power package designs can find applications in solid state lighting. System design aspects at the luminaire level will primarily drive packaging requirements.
- There is a drive for high voltage packages (multi-junction or multi-die) to improve driver efficiency.
- Materials constitute a large part of reducible costs. The system should be designed for reduction of raw materials. Either using less material or finding more affordable alternatives.
- Defining standard package architectures would provide more clarity and consistency to manufacturers as well as help enable the design of better process equipment.
- Packaging decisions are very important and cost varies significantly depending on package choices and methods. To a large extent the epitaxy, wafer processing, and die fabrication process steps are relatively constant and differentiation for different applications occurs at the packaging stage, hence there is a need for flexible packaging equipment and packaging lines. Consequently more flexible package designs are needed and any proposed standardization should not overly constrain manufacturers.

M.L7 Phosphor Manufacturing and Application		
This task supports the development of improved manufacturing and improved application of phosphors (including alternative down converters) used in solid state lighting. This could include projects focused on continuous processing of phosphors to increase production volume and manufacturing techniques to improve quality, reduce performance variation, and control particle size and morphology. This task also supports the developments of phosphor materials, application materials, and techniques which improve color consistency of the packaged LEDs and reduce the cost of LEDs without degrading LED efficacy or reliability.		
Metric	**2011 Status**	**2015 Target**
Batch size (kg)	1-5	>20
Cost ($/kg)		50% reduction every 2-3 years
Material Usage Efficiency	50%	90%
PSD-range Uniformity	30	10
Duv Control	0.012	<0.002
Thickness Uniformity (1 sigma)%	5	2
Cost ($/klm)		50% reduction
Device to Device Reproducibility (SDCM)	4	2
Attendee Suggested Metrics		
Cost of ownership		
Conversion Efficiency		60 – 70%
Color Control		
Chromaticity		

Roundtable Attendee Comments (M.L7)

Proposed changes to description:

- The title of this task should be changed to 'Phosphor Application' and any reference to the manufacturing of phosphor materials should be removed.
- The task description should include a statement regarding the relative cost of the phosphor and matrix materials which can vary significantly depending on the application, as well as the need for maintaining high conversion efficiency.
- The task description should include a statement regarding the need for efficient incorporation of the phosphor into the package.

Proposed changes to metrics:

- It was proposed to add the following new metrics:
    - The cost of ownership (COO) of the phosphor system.
    - Conversion efficiency, with a proposed target of 60-70% for 2015
    - Color control/chromacity.
- There currently is no standard or method to measure color reproducibility to within 2 SDCM and it is needed.

Other comments:

- This task should be focused on phosphor application which will include work on the entire phosphor system including the matrix/encapsulant, with the emphasis on reducing overall system cost and improving performance.

- Wafer level phosphor application should be considered, focusing on developing a broad range phosphor capable of correcting for any epitaxy wavelength non-uniformities. A goal for phosphor cost could be a 2-3x cost reduction by 2015.
- Currently the cost of the phosphor material can range from 30% of the matrix cost up to around twice the cost of the matrix depending on the package design/specification.
- The phosphor application cost can range from 20-40% of the overall package cost.

Solid State Lighting OLED Manufacturing Roundtable Summary

Introduction

On April 17, 2012, 16 OLED experts gathered in Washington, DC, at the invitation of the DOE to develop proposed priority tasks for the manufacturing R&D initiative. The meeting included a number of "soapbox" presentations from the participants, followed by a general discussion to define specific work needing attention. This report summarizes the conclusions of that meeting, including the proposed priority tasks, a summary of discussion points relevant to those selections (not all necessarily in support), and a short summary of the soapbox presentations.

General Roundtable Attendee Comments

- The main themes of the OLED roundtable presentations were:
    - Cost as it relates to substrate and encapsulation
    - Cost of OLED stack materials
    - Cost of entry into OLED manufacturing. Cost of tools and upfront investment as well as return on investment considering the predicted market demand.
    - Cost as it relates to yield and process improvements.
- Innovative developments in OLED manufacturing are necessary; therefore it is essential that potential projects propose novel cost reduction solutions for OLED manufacturing.
- There is no unanimous agreement on the best mechanism for cost reduction. Some indicate that cost reductions through immediate shifts towards high volume production are essential; while others argue starting small (lower investments) and building up is a better method.
- Regardless of production scale, yield is always a paramount driver of cost.
- Among attendees there is a lack of agreement on the envisioned form factor of OLED panels. Some feel that flexibility and novel features such as transparency or color tunability are important in order to capture a niche market to stimulate interest in OLEDs, consumer acceptance, and demand. Others feel that cost issues are so important that initial devices should be kept as simple as possible to achieve the lowest price point possible.
- More collaboration amongst the supply chain is essential for timely progress to performance and cost goals.
- The DOE needs to foster collaboration between OLED manufacturers and equipment and material suppliers to ensure compatibility of all systems.
- The lack of standards in the OLED industry is an area of concern.
    - If a standard OLED stack is prescribed, this could help guide tool manufacturers and substrate developers create products that are compatible with state of the art devices and useful to panel manufacturers. Further, such a standardized stack could allow panel manufacturers to compare substrate performance and manufacturing level control between various suppliers.
    - A standard panel could accelerate luminaire development and integration.
    - Standard measurement protocols and/or standards on substrate performance and materials could help guide substrate developers.
- Attendees discussed Task M.O4 Back-end Panel Fabrication but did not identify it as a research priority for OLED manufacturing.
- OLED stack material costs are very high and not likely to be excessively reduced. The main need in OLED stack materials is Core R&D in the development of higher performance materials, rather than Manufacturing-based R&D efforts.
- There is concern as to whether support for the manufacture of OLED deposition equipment (M.O1) and OLED materials (M.O3) is in best alignment with the DOE goals. There is uncertainty as to

whether the DOE objective is mainly for the U.S. manufacture of OLEDs or to support worldwide efforts in OLED manufacture that will ultimately lead to domestic energy savings.

- There is concern that the U.S. is too far behind in their panel manufacturing efforts to compete with countries that are either already beginning to produce OLED lighting products and/or are successful display manufacturers. The fact that many countries subsidize these efforts, allowing for lower cost products puts U.S. companies at a further disadvantage.
- U.S. materials manufacturers, substrate manufacturers, and equipment manufacturers can be and are quite successful.
- Well-developed display technology could be leveraged to advance OLED lighting, including display equipment, structures (top-emitting vs. bottom-emitting for example) and materials. However, OLED displays have different architectures and performance specs to meet and thus there are display tools, structures and processes which do not necessarily product good quality OLED lighting panels.
- Manufacturing of OLED lighting panels will initially be primarily through vapor deposition processes, then a hybrid approach using some solution processing as well as vapor deposition, and finally, manufacturing may rely on solution-based processing when OLED demand is high and prices are further reduced.

Proposed Priority Tasks

- The following tables provide descriptions and metrics for the proposed priority tasks. The task tables shown do not reflect any modifications suggested by roundtable attendees. All comments, including suggested changes to each task description and metrics, are provided below each of the relevant task tables. These comments represent a summarized transcript of the general commentary and require further discussion at the Manufacturing R&D Workshop. The results of these discussions will guide the DOE in soliciting projects in the LED Manufacturing R&D Program during the coming year.

M.O1 OLED Deposition Equipment		
Support for the development of manufacturing equipment enabling high speed, low cost, and uniform deposition of state of the art OLED structures and layers. This includes the development of new tool platforms or the adaptation of existing equipment to better address the requirements of OLED lighting products. Tools under this task should be used to manufacture integrated substrates or the OLED stack. Proposals must include a cost-of-ownership analysis and a comparison with existing tools available from foreign sources.		
Metric		**2015 Target**
Throughput	Overall throughput	100,000 m^2 per year
	Minimum product size	6” x 6”
	Area utilization	80-90%
	Uptime of machine	80-90%
	Speed (web)	2-10 m/min
	Cycle time (sheet)	≤ 60 s
	Yield	80-95%
Materials utilization		Dry process on sheets: 70-80% Wet process on web: 90-95%
Attendee Suggested Metrics		
Processing cost/unit		$100/m^2 or $/klm
Initial/capital cost		
Cost reduction (1x)		

Roundtable Attendee Comments

Proposed changes to description:

- This task should call out the need for the development of machines which can produce high performance OLED stacks. To show real progress toward manufacturability, this task should explain that equipment must be demonstrated on several relevant emissive layer formulations (this is more applicable to VTE or VTE-like solutions).
- There is a need for DOE to foster collaboration between OLED manufacturers and equipment and material suppliers to ensure compatibility of all systems. The task description needs to include a note that collaboration should be expected between the equipment and material industry.
- The description should emphasize the importance of reducing machine costs. The cost advantage of the proposed equipment would be difficult to define with a metric as it depends on the type of equipment and overall contribution to total cost OLED manufacture. Thus, applicants should be encouraged in the description to provide a detailed cost analysis of the proposed equipment as compared to current state of the art equipment and future needs.

Proposed changes to metrics:

- The ‘overall throughput’ metric of 100,000 m^2 per year of good product should be removed.
- The 2015 target for the ‘minimum product size’ metric should be changed to 100 cm^2 (4” x 4”).
- The 2015 targets for ‘area utilization’ and ‘uptime of machine’ should both be changes to >80%.
- The ‘speed (web)’ metric should have a 2015 target of > 2m/min.

- A metric for ‘processing cost per unit’ needs to be added. A 2015 target for this metric could be $\$100/m^2$. However, a target for this metric could be expressed in terms of dollars per square meter or dollars per kilolumen.
- ‘Initial/capital cost’ and ‘Cost reduction’ metrics could be added.

Other comments:

- There is a need for novel low cost manufacturing methods in order to enable profitable market entry for panel makers and luminaire manufacturers. The proposed manufacturing methods cannot ignore depreciation or labor costs and must be scalable and profitable from low early volumes to high future volumes.
- High volume equipment must have high efficiency and very high feed rates to achieve necessary deposition rates and cost targets. The equipment must also be flexible, robust and controllable in order to enable production at a variety of sizes and deposition rates.
- In order to reduce manufacturing costs, high volume production is essential. However, starting manufacturing at a small scale for development of the product would avoid the prohibitive initial investment required for high volume production equipment.
- Reducing the cost of OLED deposition equipment is important. Using a tool with a small footprint and developing more integrated equipment systems (even at the R&D scale) could help with these costs.
- The usefulness of manufacturers initially utilizing repurposed equipment as a stepping stone to investing in upgraded equipment is unclear.
- Moving toward low cost, high throughput automated systems is important as the machines and the necessary industry structure do exist.

M.O2 Manufacturing Processes and Yield Improvement		
Develop manufacturing processes to improve quality and yield and reduce the cost of the OLED products. Manufacturing tolerances should be defined to ensure the desired control over product performance. These process windows should be maintained over the whole substrate and be reproducible panel-to-panel.		
Metric		**2015 Target**
Reliability	Yield of good product	80-90%
Process cost		Factor of 2 reduction over current practice
Early failures in 1st 500 hour burn in		
Panel to panel reproducibility	Luminous emittance control	±10% of nominal value
	Color control (SDCM)	4
Attendee Suggested Metrics		
Total product yield		

Roundtable Attendee Comments

Proposed changes to metrics:

- The metric for 'yield of good product' should have a 2015 metric of >80%.
- The 2015 target for 'color control (SDCM)' should be changed from 4 to 2.
- A 'luminous emittance control' of ±10% of nominal value is a reasonable 2015 target.
- For the 'process cost' metric, it is agreed that the 2015 target should be consistent with the MYPP, however, the description needs to emphasize that DOE is looking for "step" and "break-through" changes equating to 10-fold process cost reductions.
- A metric for 'total product yield' is proposed. However, this metric would also affect the process cost metric as higher yield equates to lower cost.

Other comments:

- Current encapsulation processes are very expensive. Testing and improving encapsulation film is particularly an issue since testing time is very long due to the slow pace of the diffusion process.
- The need for improved test procedures and quality control for encapsulation should be added to this task. This issue is inherent to all the newer plastic films for encapsulation.
- Improvements in this task area are necessary for system-level cost reduction. Until yield can be confidently predicted, and raised to a sufficient level, investments in high volume manufacturing facilities for OLED lighting will remain high risk.
- OLED panel manufacturers need to lead collaborative efforts in this task with tool and material manufacturers to increase the potential for significant yield improvements.

M.O3 OLED Materials Manufacturing		
Support for the development of advanced manufacturing of low cost integrated substrates and encapsulation materials. Performers or partners should demonstrate a state of the art OLED lighting device using the materials contemplated under this task.		
Metric		**2015 Target**
Substrate	Total cost – dressed substrate	$\$52/m^2$
	Transmission	>85%
	Surface Roughness	Rrms < 2nm Rpv < 20nm
	Sheet Resistance	< 10 ohms/square
Encapsulation	Permeability of H_2O	10^{-6} $g/m^2/day$
	Permeability of O_2	10^{-4} $cc/m^2/day/atm$
	Cost	$\$10/m^2$

Roundtable Attendee Comments

Proposed changes to description:

- The task description needs to include the definition of a dressed/ integrated substrate and whether it includes light extraction, patterning, grid work, etc.

Proposed changes to metrics:

- The 2015 target for 'total cost – dressed substrate' should be changed to $\$50/m^2$.
- When purchased in small research-scale quantities, the base substrate material (polished ITO on borosilicate glass) without any light extraction layers is around $\$200/m^2$ and the process for the ITO deposition and patterning alone is roughly $\$50/m^2$. There is a great opportunity for major cost reduction in this area.
- The 2015 target of $\$10/m^2$ for the 'encapsulation cost' metric is aggressive but realistic. The cost of desiccant material is surprisingly high.

Other comments:

- OLED panel cost is dominated by the substrate and encapsulation.
- DOE emphasis on the quality of substrates and electrodes is a priority as it affects yield and hence cost.
- There is a need to enable novel low cost integrated substrates and encapsulation materials. This will require a diversion from OLED display industry methods for materials manufacturing.
- Substrate encapsulation should not be prioritized as it is not going to dramatically affect the overall OLED panel cost. DOE should focus on how to reduce the manufacturing costs from \$1000 to \$100 either via processes or equipment (i.e. M.O1 and M.O2).

DOE SSL Manufacturing R&D Tasks

The complete list of SSL Manufacturing R&D Tasks is below. The 2012 priority tasks identified by the SSL Manufacturing Roundtable attendees are indicated with an asterisk.

LED Tasks

***M.L1.**	**Luminaire/Module Manufacturing** Support for the development of flexible manufacturing of state of the art LED modules, light engines, and luminaires.
M.L2.	**Driver Manufacturing** Improved design for manufacture for flexibility, reduced parts count and cost, while maintaining performance.
***M.L3.**	**Test and Inspection Equipment** Support for the development of high-speed, high-resolution, non-destructive test equipment with standardized test procedures and appropriate metrics.
M.L4.	**Tools for Epitaxial Growth** Tools, processes and precursors to lower cost of ownership and improve uniformity.
M.L5.	**Wafer Processing Equipment** Tailored tools for improvements in LED wafer processing.
***M.L6.**	**LED Packaging** Improve back-end processes and tools to optimize quality and consistency and to lower cost.
***M.L7.**	**Phosphor Manufacturing and Application** This task supports the development of improved manufacturing and improved application of phosphors (including alternative down converters) used in solid-state lighting.

OLED Tasks

***M.O1.**	**OLED Deposition Equipment** Support for the development of manufacturing equipment enabling high speed, low cost, and uniform deposition of state of the art OLED structures and layers.
***M.O2.**	**Manufacturing Processes and Yield Improvement** Develop manufacturing processes to improve quality and yield and reduce the cost of OLED products.
***M.O3.**	**OLED Materials Manufacturing** Support for the development of advanced manufacturing of low cost integrated substrates and encapsulation materials.
M.O4.	**Back-End Panel Fabrication** Tools and processes for the manufacturing of OLED panels from OLED sheet material.